Seasonal Impacts of Land Use Practices on Water Quality in Ngoma District, Rwanda

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Abstract:** This study examined physico-chemical and microbiological parameters in water from Ngoma, Rwasaburo and Rukira watershedsin Ngoma District which are subjected to different land uses. Sampling sites were chosen in proximity to residential and agricultural areas. All analyses were performed at Institute of Agriculture, Technology and Education, Kibungo (INATEK). The pH was lower in wet season as compared to dry season in Rwasaburo and Ngoma watersheds and the vice versa was in Kinuka watershed. In all the sites, the pH levels were not significant(p = 0.78). Conductivity and hardness were lower in rainy season than in dry season in all sites and the differences between seasons were significant (conductivity: p = 0.02; hardness: p = 0.35). TDS and turbidity were higher in rainy season than in dry season in all sites and the difference were not significant (TDS: p = 0.13, turbidity: p = 0.11). Total coliforms were lower in Rwasaburo and higher in Kinuka and Ngoma area in the rainy season than in dry season and the difference was not statistically significant (p = 0.39). Escherichia coli and enterococci were higher in the rainy season than dry season in all sites and the differences were not significant (E.coli: p = 0.64; enterococci: p = 0.44). The pH, TDS and hardness values were all below the WHO and Rwanda standard guidelinesin all seasons. TDS and turbidity levels were higher than the WHO and Rwanda standard guidelines. All microorganism indicators were higher than the WHO and Rwanda standard guidelines in water in all seasons. This comparison indicatespollution of water is due to anthropogenic activities within the watershed. The water from these watersheds needs further treatment before it can be suitable for human use. Regular physico-chemical and biological analyses on the water quality in this area should be done.

Keywords: Water quality, land use practices, physico-chemical parameters, Kibungo, Rwanda

1. INTRODUCTION

Water pollution is a phenomenon that is characterised by the deterioration of the quality of water as a result of various human activities (MINIRENA, 2011). Water quality is used to describe the condition of the water, including its chemical, physical and biological characteristics, usually with respect to its suitability for a particular purpose (i.e., drinking, swimming or fishing). Water quality is affected by polluting substances that can directly or indirectly affectvarious organisms (including humans) and the environment (UNEP, 2009).

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Ngoma district is endowed with a dense hydrological network comprising of numerous small rivers, streams and wetlands that drain into lakes and other reservoirs. The different water sources in the district are (i) precipitation (natural flow of rainwater), though unevenly distributed, dictates half of the water required for agricultural activities (essentially farming) and that stored for use during shortage (MINIRENA, 2011), (ii) surface water bodies that include lakes (Birira, Mugesera, Rweru and Sake), rivers (Rwampaka, Kavubiro, Gatoro, Kagusa, Kinuka, Nyacyonga), streams (Murugando, Rusasa, Nyakagezi, Kinuka) and wetlands (Kibaya, Mutenderi and Rwasaburo), (iii) ground water that accounts for 86% of safe drinking water supply in rural Rwanda and Ngoma district in particular.

Although ground water is deemed safer than surface water, increasing pollution from agro-inputs (through leaching and erosion), and declining ability of ecosystems to naturally purify water, raise quality concerns (MINIRENA, 2011) and (iv) Wetlands which serve as reservoirs and purifiers of fresh water and help to maintain the quality of surface and ground water and regulate micro-climatic conditions through moisture recirculation, and cooling of surrounding areas (MINIRENA, 2011).

Landscape properties such as basin conditions, channel slope and aspect, local geology, vegetation, and hydrography all affect the structure and function of aquatic ecosystems. One of the most significant determinants of water quality however, is land use and cover (Dabrowski et al, 2012). Land use and management practices affect the quantity and quality of runoff water and, in turn, the water budget, water chemistry and biodiversity of aquatic organisms in receiving waters (Environment Canada, 2001). The type of land uses significantly influences the quality of water in a given environment or watershed. The common land use practice is agriculture, which include farming and livestock keeping. Agriculture is the cause of degradation and pollution of aquatic systems (Griffith et al. 2002) because it may contribute to high concentrations of nutrients, (particularly nitrogen and phosphorus); pesticides and endocrine disrupting substances (Chambers et al. 2000). Presence of these pollutants can in turn affect biota through changes in species composition and degradation of habitat. In addition, they make water unfit for the intended use. For example, increased production of cereal crops and livestock have a profound influence on stream chemistry and can affect springs and stream discharge, temperature, channel characteristics, bed disturbance regime, and organic matter input (U.S. EPA, 2010). These negative effects seem to increase as agricultural intensity increases as well. Both agricultural land usage and municipal and residential wastes (solid and liquid) have the potential to degrade water quality.

Quality of water can be determined by analysing the levels of physico-chemical (pH, conductivity, Total Dissolved Solids (TDS) and suspended solids) and biological parameters of waterand comparing with the world or national standards set depending on the use of the water (U.S. EPA, 2010). The acidic or basic characteristics of wateror pH (APHA, 2014) is affected by biological availability and solubility of elements in water (U.S. EPA, 2013).TDS represents the total concentration of minerals (carbonates, nitrates, bicarbonates, chlorides and sulphates salts of calcium, magnesium, potassium and sodium)which have both natural and anthropogenic source.Monitoring the TDS level and the pH of drinking watercan provide an early warning signalin water quality for immediate action (Health Canada, 2007).

Conductivity, which describes the ability of an aqueous solution to carry an electric current (APHA, 1998), is affected by the type of rock and soil within the watershed and watershed size. Water with mostly inorganic compounds tend to be better conductors than those with organic compounds (APHA, 2014). The amount of ions or total dissolved salts in water is an indicator of water quality as well as conductivity, and it increases as the concentration of ions increases (Tchobanoglous, 1985). Turbidity is a measure of the relative clarity or cloudiness of water. The way the particles interfere with light transmittance depends on the size, shape, number, composition, colour and refractive index of the particles, the wavelength (colour) of light that falls on them as well as the refractive index of the water.

Though the interaction is complex, the intensity of light scattering increases as the turbidity increases (APHA, 2014). Despite the fact that it is not a direct measure of suspended particles, turbidity is a general measure of the scattering and absorbing effect that suspended particles have on light (Health Canada, 2007). Hardnessof water can also be a measure of water quality. Water hardness is the traditional measure of the capacity of water to react with soap and is commonly expressed as milligrams of calcium carbonate equivalent per litre.

Pathogen contaminants of aquatic ecosystems that originate from municipal, residential and agricultural wastes (Environment Canada, 2001) are mainly water borne pathogens. Theseinclude bacteria like Salmonella typhi (cause typhoid fever), Vibrio cholera (cause cholera) andEscherichia coli (E.coli), protozoans like Giardia lamblia (cause beaver fever) and Cryptosporidium parvumas well asand viruses like Hepatitis A virus and the Norwalk virus (Dabrowski et al., 2012). Presence of these disease causing pathogens in water decreases their quality and threaten biodiversity by causing diseases to human population.

The main water sources located in Kibungo and Rukira watersheds in Ngoma DistrictareGasoko, Nyamuganda and Rwasaburo springs. They are the important water sources in the area for humans and livestock, irrigation water for agricultural use, as well as providing a source for recreation. In terms of land use, agriculture represents a large portion of the land use in Ngoma District and mainly around the watersheds. In addition to municipal waste water effluent from the Kibungo sector, runoff from agricultural lands has implications on the water quality of the head springs and streams. Despite the importance of these springs to the livelihood, health and well-being of the inhabitants of the watersheds, very little is known and no effort has been made to evaluate the effects that land use or wastes effluent might have on overall water quality of these springs. The objective of this study was to evaluate the effect of land use in three watersheds on water quality in Ngoma district.

MATERIALS AND METHODS

2.1 Sampling Areas

Rwanda's topography (Figure 1)is characterized by a vast number of hills and mountains, a fact which results in high soil erosion and loss of water. The country possesses a dense hydrographical network where lakes occupy 128,190 ha; rivers cover an area of 7,260 ha and water in wetlands and valleys cover a total of 77,000 ha.The Congo-Nile Ridge divides the country into west and east; where to the West of lies the Congo River Basin that covers 33% of the territory and provides 10% of the total national waters. To the East lies the Nile River Basin, which covers 67% of the territory and provides 90% of the national waters (MINIRENA, 2011).

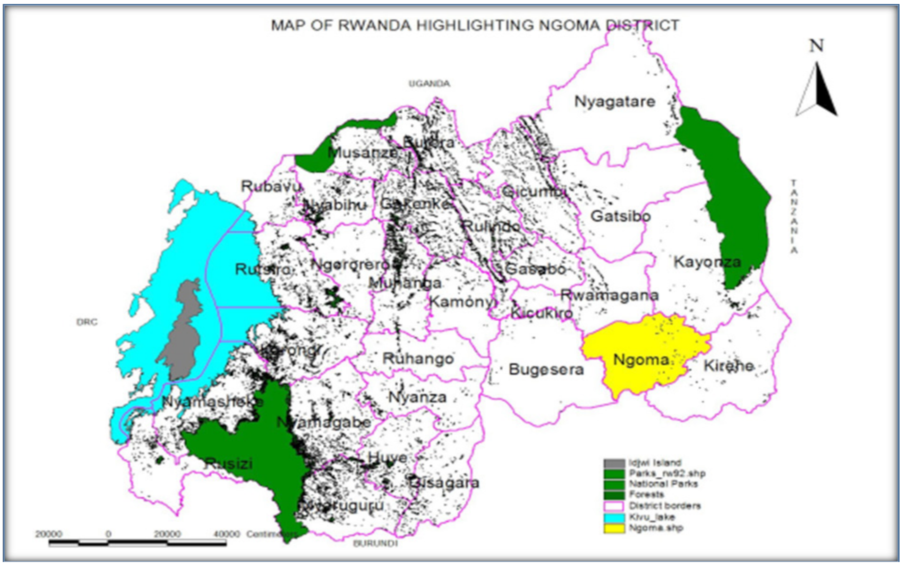

Figure 1: Map of Rwanda showing the Topography and the Ngoma District (Our own design using Arcview 3.2.a Software)

The study was conducted in Rukira and Kibungo sectors in Ngoma District, Eastern Province, Rwanda. Three springs (Kinuka, Ngoma and Rwasaburo) were chosen as sampling sites based on surrounding land use in the Rukira and Kibungo Watersheds. Kinuka spring, located in Buriba Cell, is located in the Rukira sector and is freely accessed by humans and livestock (Table 1). This spring is used as a source of untreated water for the Rukira Sector population of approximately 2,400 people. Despite the cooperative's KoperativeDufateAmaziNezaRukira (KODANERU), efforts in managing the spring, anthropogenic related wastes have been observed near the spring. Ngoma and Rwasaburo springs are located in Kibungo Sector, the capital of the district. A large proportion of water used in Kibungo is from Rwasaburo spring. The district also dumps its sewage into the lands surrounding the springs. The entire watershed is cultivated and used to produce crops such as beans and banana (Table 1).

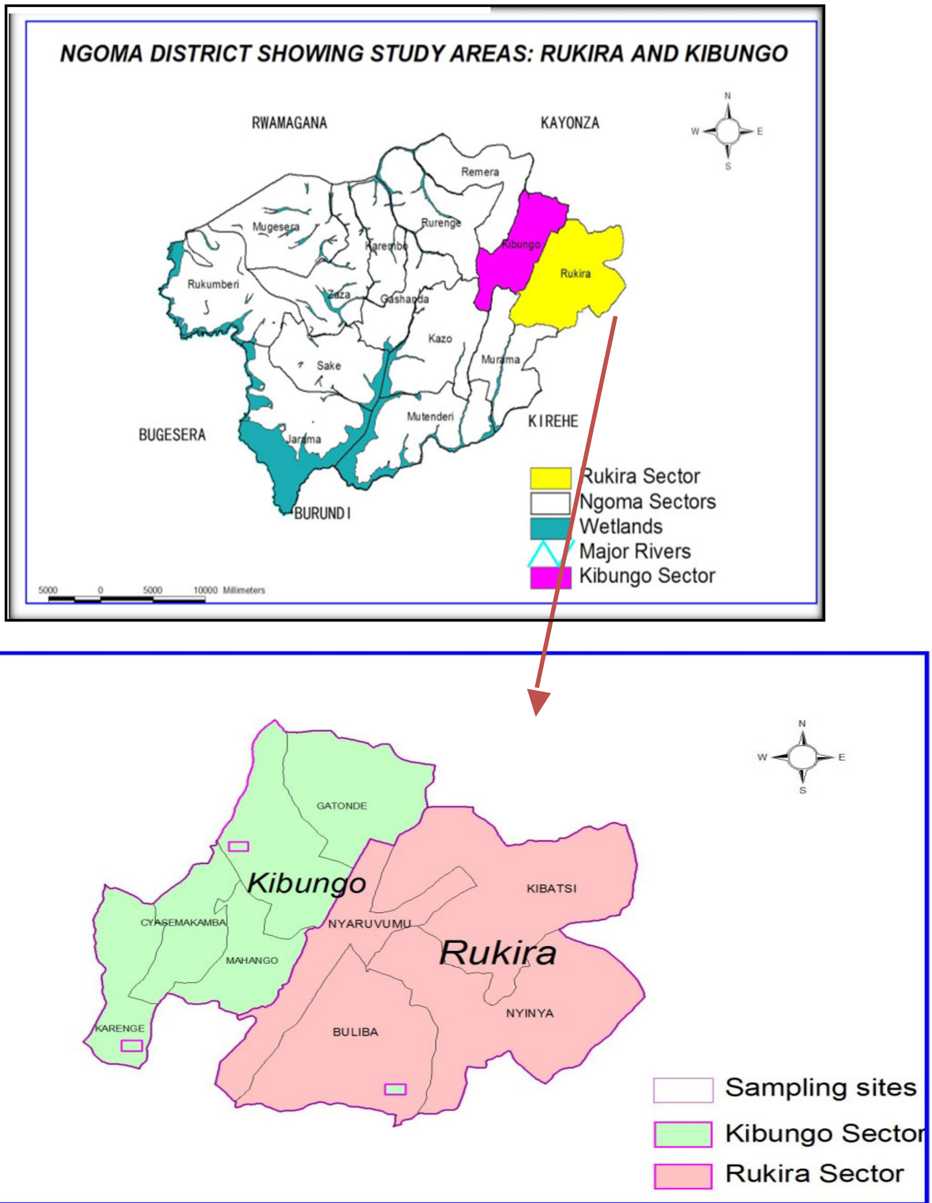

Figure 1: Map showing the Ngoma District and Kibungo and Rukira Sectors as sampling area (Own Design using Arcview 3.2.a Software)

Rwasaburo spring, located in Karenge Cell, is a source of untreated water for the Kibungo sector population of an approximately 22,000. Ngoma spring in Kibungo Sector serves an approximate population of 650 persons. Table 1 and Figures 3-5 show the description of the sampling sites in the study.

Table 1: Sampling sites description

Name of source	Height (m)	Surrounding land use practice
Ngoma	1474 m	Agriculture, cattle keeping, Schools, Health centres, markets, industries and human settlements
Kinuka	1639 m	Agriculture, cattle, Schools, Health facilities, markets and human settlements
Rwasaburo	1441 m	Agriculture, cattle keeping, Schools, Hospital, prison, markets, industries and human settlements

Figure3: Rwasaburo Land use and sampling site

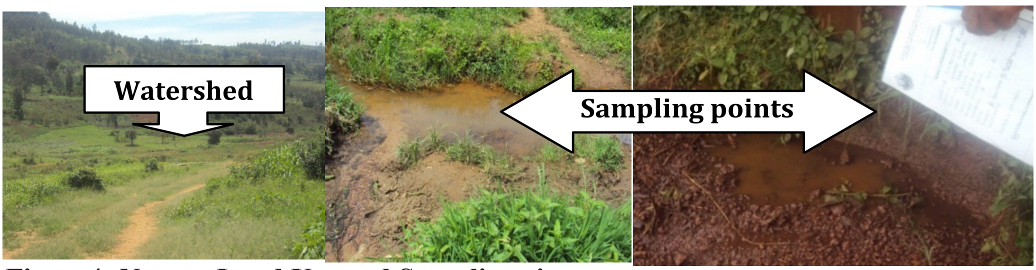

Figure4: Ngoma Land Use and Sampling site

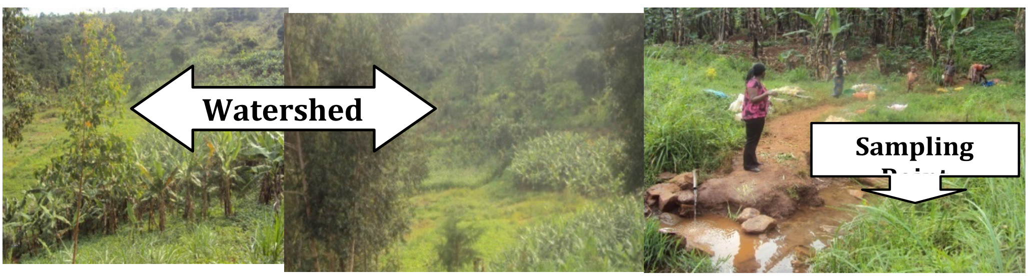

Figure 5: Kinuka Land Use and Sampling Site

2.2 Sample Collection

Sampling was done directly from the spring during rainy (April 2014) and dry (July 2014) seasons in triplicate and without filtration. Samples were collected using either a 1 litre or a 4 litre sterilized high density polypropylene (HDPP) bottles (NalgeNunc International, Rochester, New York), depending on the depth of the spring. The pH, conductivity and turbidity were measured immediately after sample collection. The samples were later placed in a cooler (4-8 °C) and transported to the Institute of Agriculture, Technology and Education,Kibungo (INATEK) Water Laboratory where they were kept in a refrigerator before analysis.

2.3 Determination of Physico-chemical Parameters

All samples were analysed within 24 hours after collection according to APHA (2014). The pH and conductivity were measured using a Portable Multiparameter Water Quality (HI 9829), as recommended (APHA, 2014). A microprocessor turbidity meter, H1 93703 was used to measure turbidity and was calibrated with standard solution 10 nephelometric turbidity units (NTU), 200 NTU and 999 NTU prior to measurement. Then, a cell containing distilled water was used as blank to ascertain the zero measurement. Total hardness was measured using HI 98202 Water Hardness/ Softness Tester and Total Dissolved Solids (TDS) were measured using the Waterproof ExStikMultimeter.

2.4 Microbiological Analyses of Pollution-Indicator Organisms

Escherichia coli and Enterococci as well as Total coliforms apollution-indicator organisms were determined using membrane filtration method and standard plate count (WHO, 2010). A sample (50 mL) was filtered on a Millipore filter paper and placed on a pad nourished with Slanazt and Bartely. The petri dishes were closed and incubated in laboratory incubator at 44 °C for 16 hours. The results were obtained by counting yellow colonies developed on filter paper and reported in number of colony forming units (CFU) per 100 mL of water.

2.5 Data analysis

Analysis of the water quality data was done by calculating means and standard deviations using Spreadsheet of the Microsoft Windows. Further analysis to determine the differences in seasonal and inter-site variations in the analysed parameters was analysedby Student's t-test using Statistical Package for Social Sciences (SPSS) version 20. All samples were presented as tables and graphs as shown in the next section.

3 RESULTS AND DISCUSSION

3.1 Current land use practices in the study area

Based on the conversation by district officials and direct observation, land in the study area is used mainly for agricultural purposes, representing 81% of all practices, followed by settlement that represents 30%. Agricultural activities therefore represented the main source of water pollutants in the Ngoma district. These findings are consistent with the results obtained from a study conducted by NISR (2010). According to NISR (2010), 32.5% of households in Ngoma district still use an unimproved drinking water source that can contain different harmful contaminants.

The high percentage of pollutants and therefore more anthropogenic activities have a correlation with the water quality in the area as shown in Figure 6.

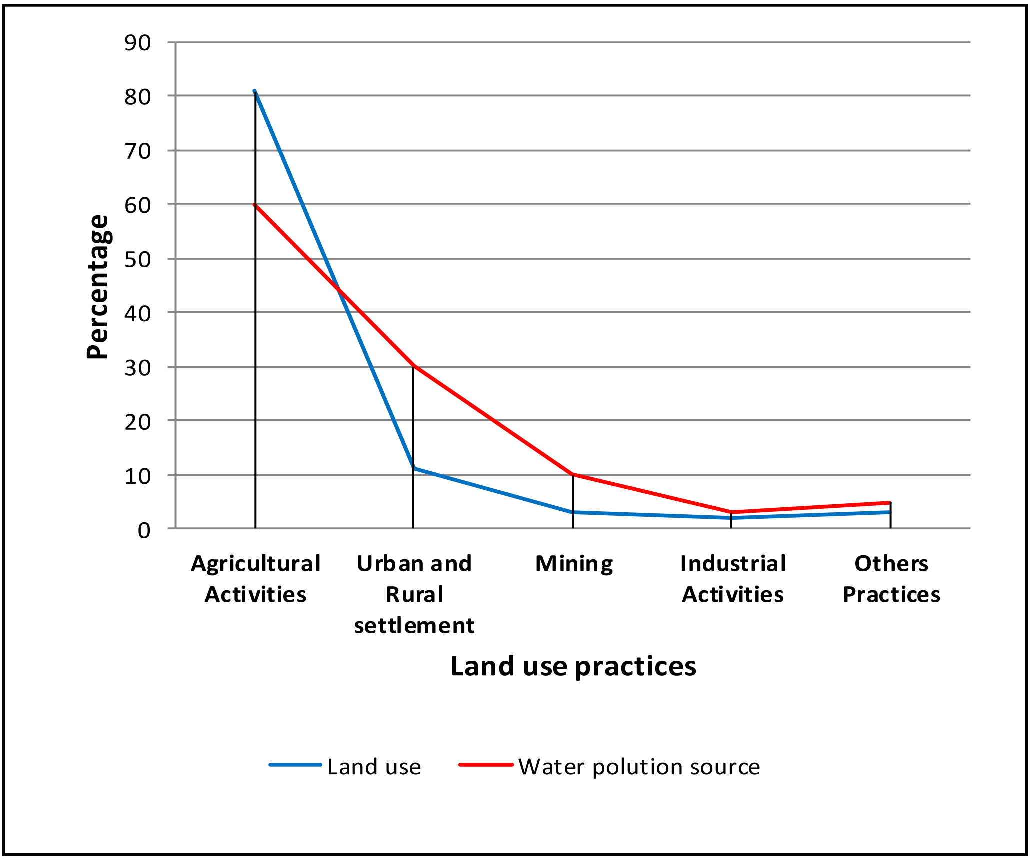

Figure 6: Current land use practices in the area and their contribution to water pollution

3.2 Physico-chemical Water Parameters in Water

Table below gives the results of the observed physico-chemical parameters of the water from the three watersheds.

Table 2: Variation in the Physico-chemical Parameters of Water in the Study Area

Sampling site	Season	pH	Conductivity (µS/cm)	TDS (mg/L)	Turbidity (NTU)	Hardness (mg/L)
Rwasaburo	Rain season	5	196	1002	7.1	225
	Dry season	5.2	340	843	5.5	273
Kinuka	Rain season	5.2	212	900	8.9	210
	Dry season	5.0	420	750	5.4	250
Ngoma	Rain season	5.2	190	1098	6.5	170
	Dry season	5.3	380	947	5.7	270
WHO Guidelines	All seasons	**6.5-8.5**	**1500**	**700**	**5**	**300**
Rwanda Standards	All seasons	**6.5-8.5**	**1500**	**700**	**5**	**300**

3.2.1: pH

Whereas pH was lower in wet season as compared to dry season in Rwasaburo and Ngoma sites, the vice versa is in Kinuka spring (Figure 7). In all the sites, the levels were below the WHO and Rwanda standard guidelines.

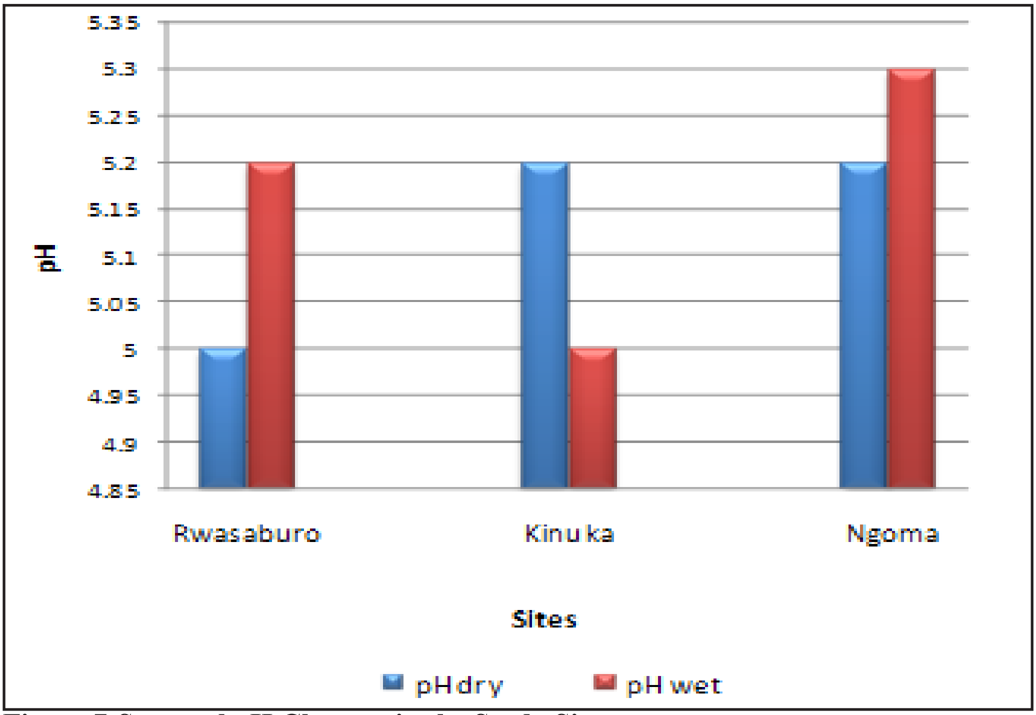

Figure 7:Seasonal pH Changes in the Study Sites

There was no significant difference in pH of water between sites (p = 0.78) and seasons (p > 0.06), suggesting that land practices that involve changes in pH are not impacting on water quality as far as pH is concerned. Decomposing organic matter produce carbonic acid,can cause increase in acidity. The observed results also indicate that the socio-economic activities in the study area produce adequate decomposing material that warrant reduced pH changes.

A change in the pH of water can result to acidification of the environment where many plants and animals can be harmed, or even killed. Acidic water can cause problems for human consumption. While slightly acidic water is not dangerous, on its own, it can be quite dangerous when combined with other compounds. Water with a pH that is less than 6.5 can leach metal ions, (iron, manganese, copper, lead and zinc) from the environment. On the other end, water with pH greater than 8.0 can be difficult to disinfect as the water cannot allow effective chlorination (WHO, 2011).

3.2.2: Conductivity

Conductivity was lower in rainy season as compared to dry season in all sites (Figure 8). The difference between conductivity in dry and wet season was significant (p = 0.02). Conductivity in all the studies sites were below the WHO and Rwanda Guidelines of 1500 µS/cm (Table3).

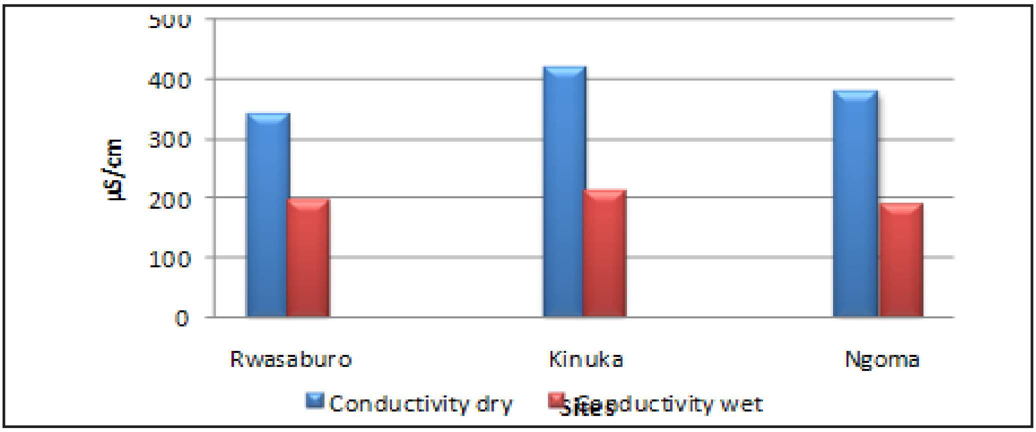

Figure 8: Seasonal Water Conductivity Changes in the Study Sites

Kinuka had the highest average conductivity probably due toland uses and watershed development in the surrounding environments. Higher conductivity was linked to human activities as well as presence of inorganic anions (chloride, nitrate, sulphate, and phosphate), cations (sodium, magnesium, calcium, iron, and aluminium) and increased temperature. The observed trend in conductivity between the seasons could indicate combined effects of these factors and this is an indicator of a discharge or some other source of pollution within a watershed (U.S. EPA, 2014).

3.2.3: TDS and Turbidity

Unlike the conductivity, TDS and turbidity were higher in rainy season than in dry season in all sites (Figures9 and 10). The difference in TDS and turbidity between seasons in all sites was not significant (TDS: $p = 0.13$, turbidity: $p = 0.11$). The levels were higher than the WHO and Rwanda standard guidelines set for TDS (700 mg/L) and turbidity (5 NTU) in surface water (Table 3).

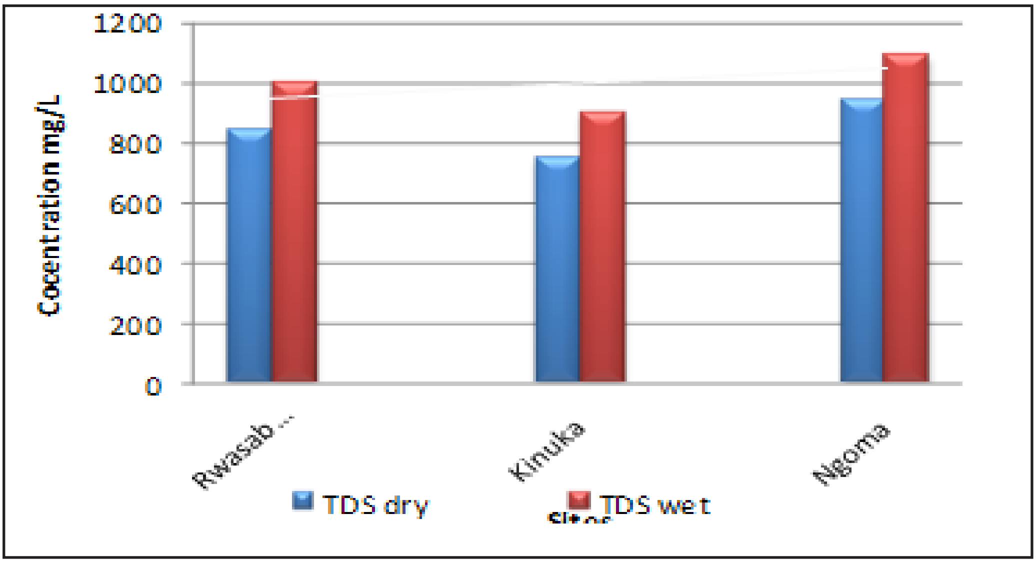

Figure 9: Seasonal water TDS changes between Sites

Significant differences in total dissolved solids (TDS) were observed between seasons indicating that water sources have more suspended particles in the rainy season than dry season. The high value observed in rainy season could be due to erosion as a result of removal of vegetation cover. When the soil is stripped off its vegetative cover it becomes susceptible to wind and water (INATEK, 2012). Surface runoff becomes loaded with sediments which are in turn deposited in water sources. In addition, the observed difference can be due to effluent which contains domestic and agricultural wastes discharged in the surrounding watershed. A high concentration of TDS is also an indication that harmful contaminants, such as iron, manganese, sulphate, bromide and arsenic, can also be present in the water. This is a concern when the excessive dissolved solids are added to the water column as human pollution, through runoff and wastewater discharges (Saskatchewan Environment, 2006).

These solidsnot only increase turbidity but also can cause the water to be turbid. Turbidity measurement is a valuable indicator of water quality as is an indicator of the effectiveness of drinking water treatment processes, particularly filtration, in the removal of potential microbial pathogens. High turbidity measurements or measurement fluctuations can be indicative of inadequate water treatment and/ or a problem in water quality (Health Canada, 2007).

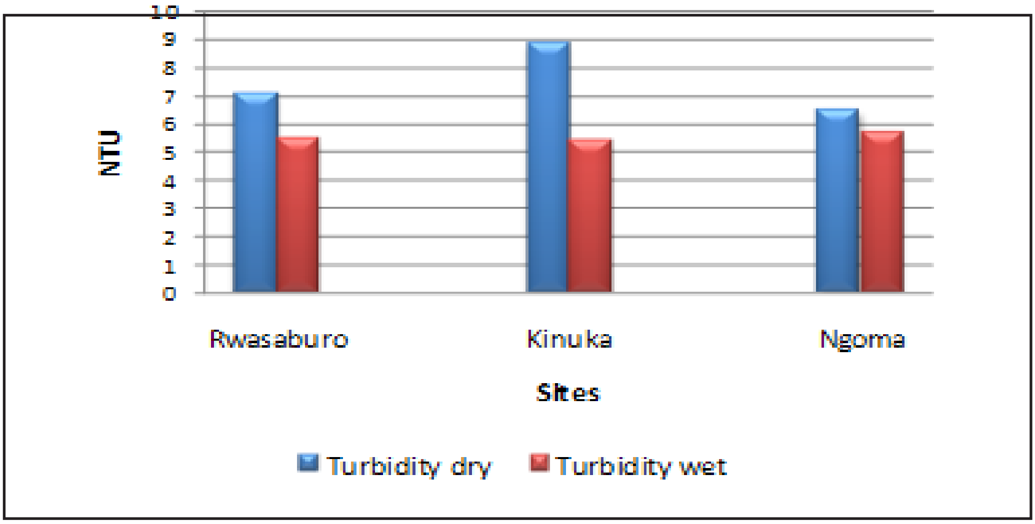

Figure 10: Seasonal Water Turbidity Changes in Study Sites

TDS and turbidity are related to human activities in surrounding watersheds. The transported materials in water include wastes from homes and agricultural activities. The results suggest that presence of these materialswithin the catchment contribute to water quality deterioration by decreasing TDS and turbidity.

3.2.4: Hardness

Rainy season hardness was lower than dry season hardness in all sites. This difference was not significant ($p = 0.35$) and was lower than the set guidelines for WHO and Rwanda standards of 300 mg/L (Figure 11).

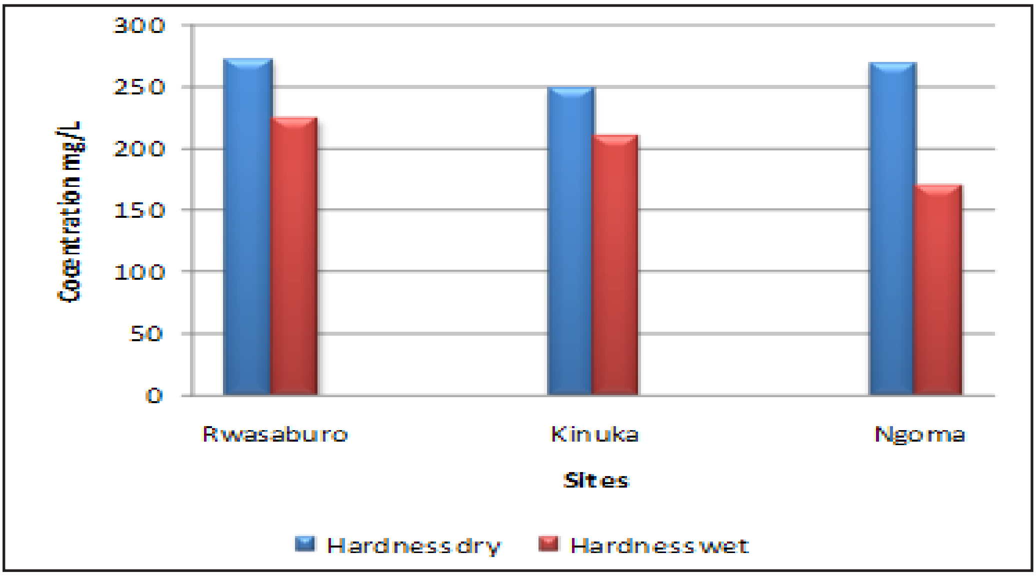

Figure 11: Seasonal Changes in Water Hardness in the Sites

The natural source of hardness in water is dissolved polyvalent calcium and magnesium ions in form of limestone and chalk from sedimentary rocks, seepage and runoff from soils (WHO 2011). The observed resultssuggest that land practices are not impacting on water quality as far as hardness is concerned.

Water containing calcium carbonate at concentrations below 60 mg/L is generally considered as soft; 60–120 mg/l, moderately hard; 120–180 mg/l, hard; and more than 180 mg/l, very hard (McGowan, 2000). Water with too low hardness has low levels of beneficial ions (calcium and magnesium) and can be corrosive, leaching out copper and lead of plumbing pipes. Too high hardness can have an unpleasant taste, can dry out skin and cause scaling on fixtures and throughout the water distribution system. The scaling decreases the efficiency of plumbing systems, which results in greater power consumption and increased costs (SDWF, 2013).

3.3: Biological PollutionbyIndicator Organisms

Three pollution indicator organisms: total coliforms, Enterococci and E. coli, were determined and the results are shown in Table 4 and further represented in Figures 8-10. Total coliforms were lower in Rwasaburo and higher in Kinuka and Ngoma area in the rainy season than during the dry season (Table 3). The difference between the dry and wet seasons was not statistically significant ($p = 0.39$). There were higher levels of Escherichia coli in the rainy season samples in all sites as compared to dry season (Table 3) and the difference was not statistically significant ($p = 0.64$). While there were higher levels of enterococci in Kinuka and Ngoma sites in rainy season compared to dry season, there was no difference in the levels of these indicator organisms in Rwasaburo site between seasons. Like E.coli, the difference in the levels of enterococci between seasons was not significant ($p = 0.44$).

Table 3: Seasonal Variations of Indicator Organisms in the Study Area

Sampling site	Season	Total coliforms (CFU/100ml)	*Escherichia coli* (CFU/100ml)	Enteroccocis (CFU/100ml)
Rwasaburo	Rain season	26	24	2
	Dry season	30	20	2
Kinuka	Rain season	330	76	7
	Dry season	180	50	2
Ngoma	Rain season	520	370	38
	Dry season	200	210	10
WHO Guidelines	All seasons	0	0	0
Rwanda Standards	All seasons	0	0	0

The seasonal and spatial variations of the three indicator organisms in the study area were in a similar fashion. This is to be expected as E. coli and Enterococci because they are a subset of the total coliform bacteria group.Thelowest number of total coliforms were observed Rwasaburo spring (Figures12-14). This can be explained by the fact that the marshland in which it is located is managed and protected, and that the human influence in the watershed is minimal.

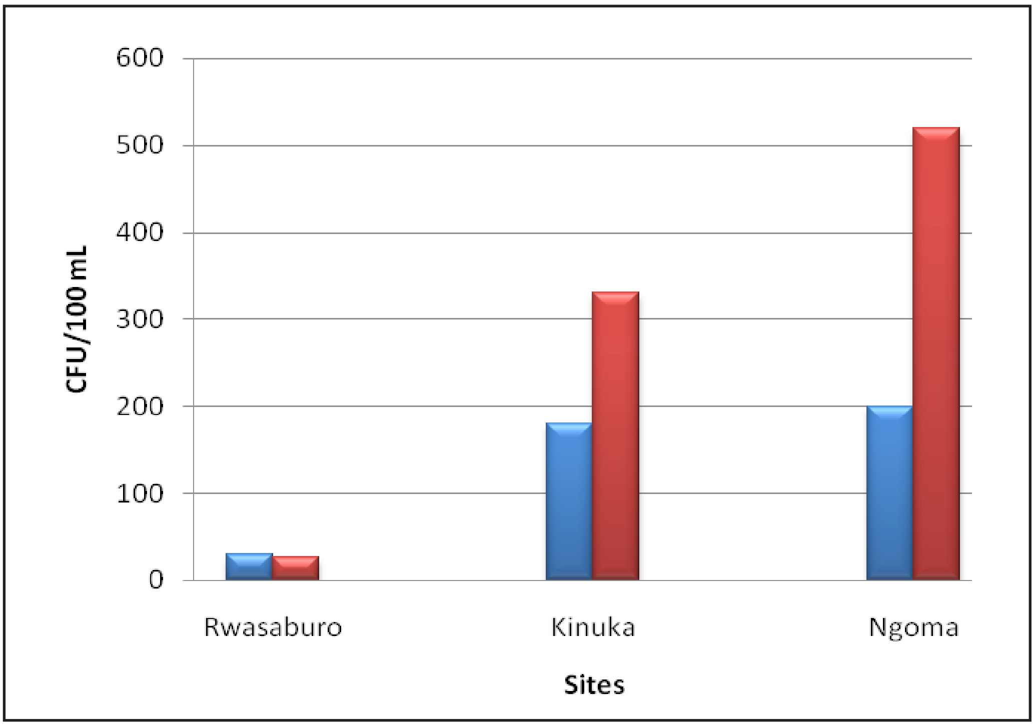

Figure 12: Seasonal Variation of Total Coliform in Different Sites

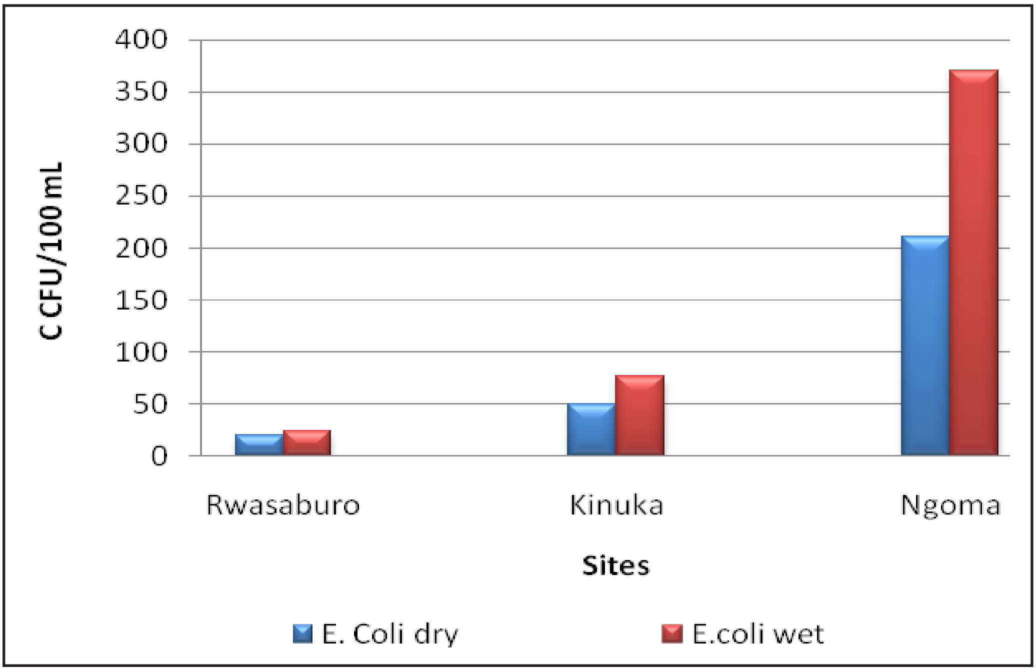

Figure 13: Seasonal Variation of E.coli in the Study Sites

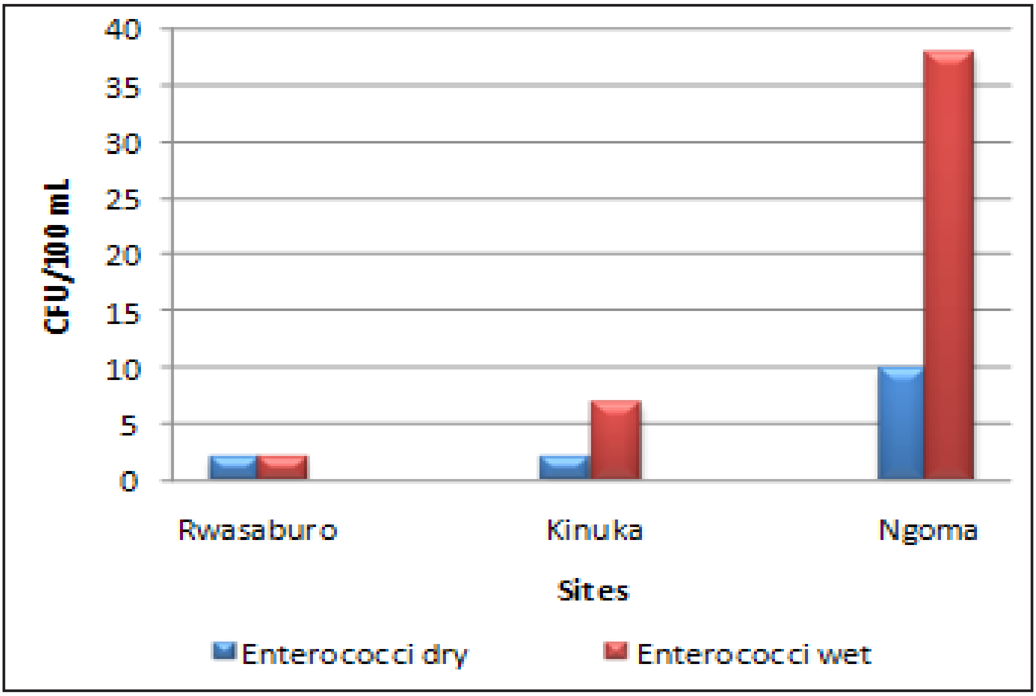

Figure 14: Seasonal Variation of Enterococci in the Study Sites

High levels of the measured pathogens were observed at Ngoma Site (Figures 12-14). This is probably influenced by municipal wastes dumping in the surrounding watershed, dairy operations and current residential development. High levels of biological contamination were expected in rainy season because of the rain events during this season which increases agricultural and livestock activities in the surrounding watersheds. The survival of microbiological pathogens, once discharged into a water body, is highly variable depending on the quality of receiving waters, particularly turbidity, oxygen levels, nutrients and temperature.

WHO guidelines for drinking water quality stipulate zero coliforms per 100 ml to be safe limit if water is used for drinking. The range from 2 to 520 coliforms/100 ml is above the stipulated guidelines. The results obtained are consistent with the findings by INATEK. (2012), where faecal coliforms ranged from 7 to 720 CFU/100 ml of water sources in Ngoma District. This indicates that human activities are contributing to biological pollution. That implies an increased treatment costs to prevent water bone diseases. The results are in agreement with the recent periodic elevated measurements of biological contaminants in Kibungo hospital and Rukira, Kibungo and Gituku health centres (INATEK, 2012). The high rate of waterborne diseases observed depicts a correlation between these diseases and the water consumed by the surrounding population.

3.4: The Effects of Land use practices on the water quality

Increased housing developments, associated with urbanization in Kibungo and to a lesser extent in other sectors in the District directly affect the soils' physical characteristics thus lowering water infiltration and increasing runoff and soil erosion with increased potential for floods. Roofing of housing complexes and paving of roads and other access routes has reduced the surface area available for soil infiltration. During the rainy season much of the run-off flows to the valleys below with minimal infiltration which is one of the main ground water recharge pathways.

The direct impact of reduced soil infiltration is increased run-off, soil erosion on bare soils and siltation of water ways in the lower slopes or marshlands. Also associated with urbanization is watershed destruction and increasing incidences of dumping of untreated effluent in rivers and marshlands.

In Ngoma District, especially in Ngoma town, wetlands are most likely to be used as dumping sites for wastes. For the case of Kinuka and Rwasaburo wetlands for Ngoma District, the rain water carries a variety of wastes from the existing open sewers, exposed drainage canals and domestic sources directly into the marshlands in lowlands.

3.5: Soil erosion and Microbial contamination

There is a significant relationship between land protection and microbial water contamination. Once the area is more protected, the less is water contaminated (Figure 15). These finding are not substantially different from those of Griffith et al. (2002) regarding water pollution.

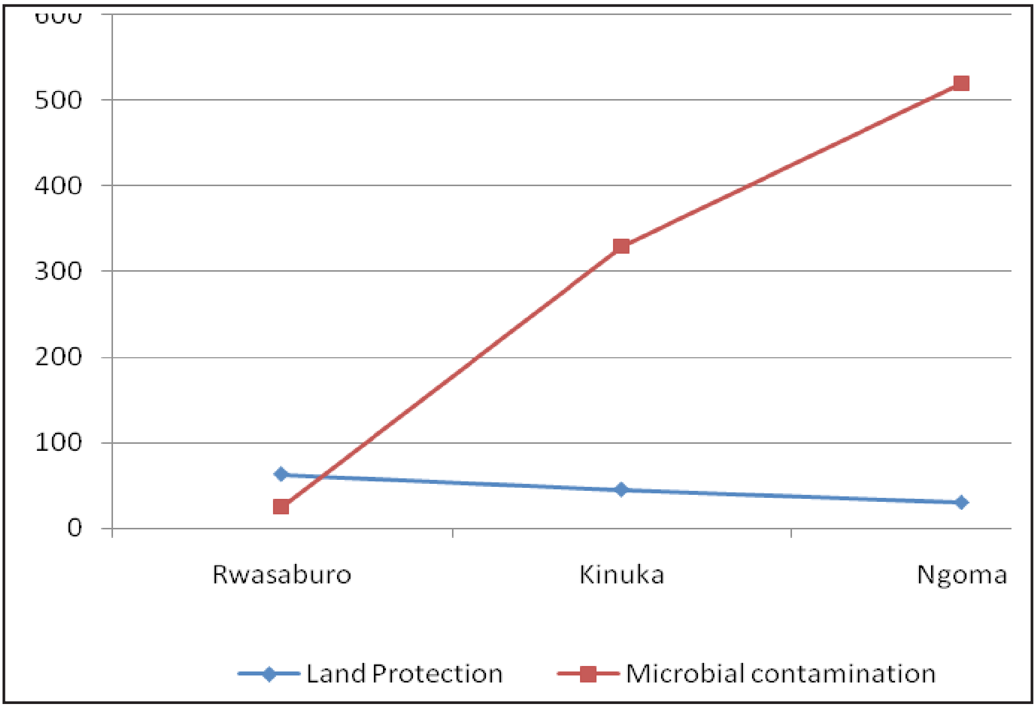

Figure 15: Relationship of Land Protection against Erosion versus Total Coliforms Contamination Levels

Agricultural activities are among the main sources for degradation and pollution of aquatic systems. According to REMA (2012) in a similar research, more than 95% of the arable grassland in western Rwanda has been converted to production of cereal crops and livestock using intensive agricultural practices that are environmentally damaging the conversion of adjacent watersheds areas and native grasslands to crop and pasture land can have a profound influence on stream chemistry and also affects stream and springs discharge, temperature, channel characteristics, bed disturbance regime, and organic matter input. These physical changes in turn affect stream biota through changes in species composition, and degradation of habitat.

These negative effects seem to increase as agricultural intensity increases as well. The major pollutants arising from agricultural lands are microbial contaminants, particularly coliform (Table 4). The presence of these pathogens makes water unfit for use by humans, and destroys habitat.

4 CONCLUSION

Higher levels of physico-chemical parameters in rainy season that correlates well with increased biological parameters have a link to observed increasedoutbreak of infectious diseases like cholera and malaria. These findings suggest that anthropogenic activities are responsible in polluting the water within the study area. Contamination of water has impacts of increasing prevention and treatment costs due to water bone diseases outbreaks for rural communities who use the water for drinking, bathing, or watering fruits and vegetables. Since the levels are higher than the set standards, thewater need further treatment before can be suitable for human use.Since endemic outbreaks may cost more than water treatment in future, it is better prevent them occurring to avoid incremental costs in the future. It is advised to construct at least one water treatment plant in each sector to provide safe water. In addition, further detailed physico-chemical and biological analyses should be done on the water quality in this area is recommended.

5 ACKNOWLEDGEMENTS

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